The FAIR Project: Status and New Developments

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Abstract. Detailed planning and R & D for both, the accelerator and the experimental systems of the future international *Facility for Antiproton and Ion Research* (FAIR) is in progress on many fronts. It involves a wide range of activities, both at laboratories in partner countries participating in the preparatory activities as well as at GSI.

This report summarizes the current situation, with emphasis on recent important developments. This includes new performance aspects of FAIR, in particular also the plans towards QCD spin physics with polarized anti-protons. An outlook on facility development and construction is given.

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THE FACILITY

FAIR is a new facility planned at the German National Center for Heavy Ion Research *GSI* in Darmstadt [1]. The facility will provide intense beams of rare isotopes, relativistic heavy ions and anti-protons for a wide range of experiments in particle, nuclear and atomic physics. Table 1 shows the parameters of beams at FAIR. One key feature of the facility is the parallel operation of multiple beam types to allow a high duty cycle and a cost effective usage by many users.

The facility will comprise several storage rings equipped with beam cooling for precision measurements. After injection from presently existing accelerators the beams are injected into a 100 Tm synchrotron (SIS 100) equipped with fast cycling magnets. After acceleration particles are extracted either for the production of secondary beams or for further acceleration in a second, superconducting 300 Tm synchrotron (SIS 300) concentric to SIS 100. Protons are used to produce anti-protons, Uranium ions to create rare isotopes. An overview of the facility is given in Fig. 1.

TABLE 1. Primary and secondary beams at FAIR

Species	Intensity	Gain over present	Energy
Primary Beams			
$^{238}U^{28+}$	10^{12}/s	100 - 1000	1.5 - 2 AGeV
$^{238}U^{92+}$	10^{10}/s	100 - 1000	up to 35 AGeV
Protons	2×10^{13}/s at 30 GeV		up to 90 GeV
Secondary Beams			
RIB		1000-10000	up to 1.5 - 2 AGeV
Anti-protons	2×10^{7}/s		0 - 15 GeV

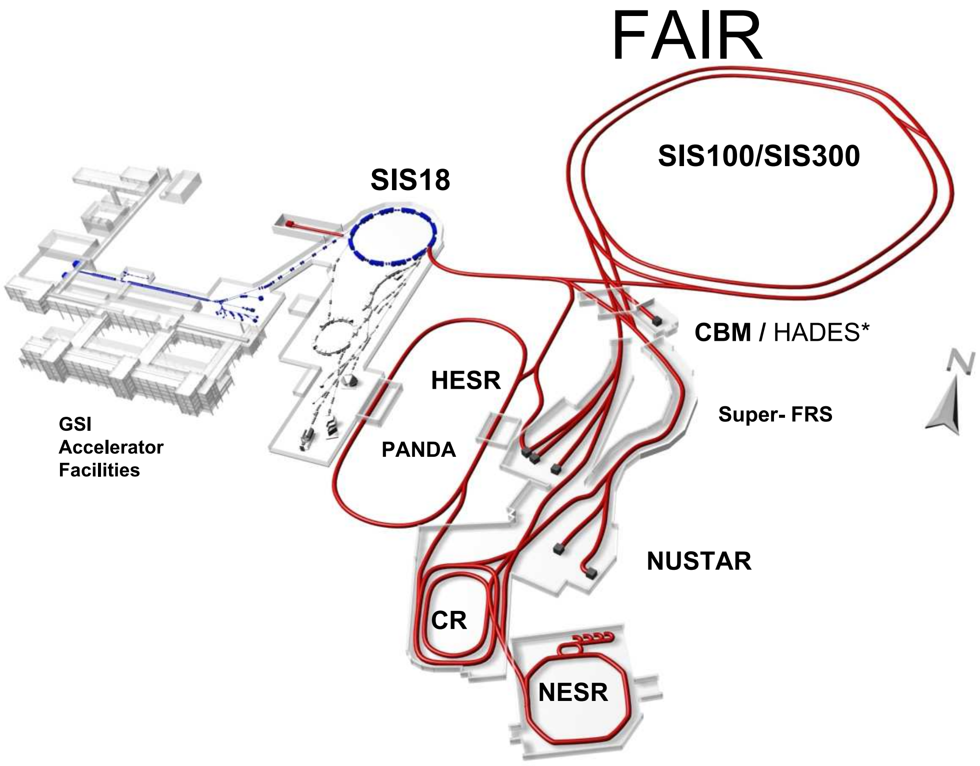

FIGURE 1. Topology of the FAIR accelerator complex.

PHYSICS PROGRAM

The new facility serves five pillars of physics research: *Rare isotope beams* are used to investigate the structure of exotic nuclei and to learn more about nuclear reactions of astrophysical importance to understand the generation of the elements and their abundances. *High energetic heavy ion beams* are used to create dense matter and study the phase diagram of the strong force. *Anti-protons* serve to study fundamental symmetries by comparing anti-matter to matter and investigate the strong interaction governing all hadronic matter. Highly bunched ion beams are used to interact with *dense plasma* to probe the physics of nuclear fusion. Finally highly charged ions and also anti-protons are used for precision measurements in *atomic physics and applied science*.

Physics with Rare Isotope Beams

The structure of nuclei far from the line of stability can be studied by using rare isotope beams. This allows to improve the understanding of processes of nuclear synthesis in stars and stellar explosions as well as to study fundamental symmetries and interactions of nuclei.

These isotopes are produced by colliding heavy nuclei like Uranium with a target and then selecting the created fragments according to their mass and charge in a fragment separator. The new superconducting fragment separator of FAIR has much higher acceptance and aperture and therefore allows isotope intensities higher by four to five orders of magnitude than the previous facility at GSI. All elements from H to U can be treated at intensities above 10^{12} ions/s at various energies both pulsed and continuous. Three experimental sections follow the fragment separator.

In the high energy branch reactions of nuclei in the relativistic domain can be studied at highest efficiency and full acceptance. This allows to record even rarest isotopes and therefore study new phenomena of nuclear structure like halo effects, new magic numbers or particular collective nuclear states.

In the low energy branch the unstable isotopes are decelerated and then captured, trapped or stopped. An energy buncher compensates the losses in energy definition due to the deceleration. With the isotopes decay spectroscopy, gamma spectroscopy or laser spectroscopy can be done and they can be studied in ion traps.

A unique facility at GSI is the in-flight study of rare isotopes. This work will be continued in an improved way in the ring branch of FAIR where both fast stochastic cooling and electron cooling will allow excellent definition of energy and orbit of the nuclei. Here Schottky and isochronous mass spectroscopy can be performed with high precision. Light ion induced reactions can be studied using a target recoil detector and gamma detector surrounding an internal target. In addition the isotopes can be collided with an electron beam or an anti-proton beam.

Physics with Relativistic Heavy Ions

The phase diagram of strongly interacting matter is a particular topic of interest for relativistic heavy ion reactions. The quark-gluon-plasma, a new state of matter at very high temperatures, was discovered at the CERN SPS and at the BNL RHIC in these reactions. It is predicted that a critical point exists in the phase diagram of QCD. However, present and future experiments at the BNL RHIC and the CERN LHC take place at too high energies to access the region of this point. An intermediate energy between 2 and 30 GeV/u is of interest for probing baryon production and the charm quark threshold in very dense matter allowing to search for the critical point in the predicted region. This is a main goal of the planned CBM experiment[2] at FAIR.

CBM will study in-medium modifications of hadrons, strangeness production, charmonium suppression by nuclear matter and event-by-event fluctuations allowing to observe the critical point. The experimental challenge is the recording of more than 1000 tracks per event at a rate of 10 MHz to detect displaced decay vertices of D-mesons and hyperons.

Radiation hard silicon pixel and strip detectors in a dipole magnet will be the core of the tracking system. Particle identification mainly of electrons will be done by a RICH detector and several TRDs serving also as trackers behind the magnet. In addition time-of-flight detectors and an electromagnetic calorimeter complement the detection system.

Physics with Anti-protons

Fundamental Symmetries

Anti-protons at very low energies are an important tool for the study of fundamental symmetries. This field is presently pursued at the CERN AD and will be continued at 100 times higher intensities and an improved system of storage rings and traps at FAIR. Main topics will be the production and trapping of anti-hydrogen and subsequent studies of CPT invariance, Lorentz invariance, gravitation of anti-matter, atomic collisions of anti-matter. By replacing electrons of atoms by anti-protons nuclei can be studied by means of precision X-ray spectroscopy.

Hadron Physics

Using anti-proton beams in a range of 1.5 GeV to 15 GeV a large range of hadronic states can be produced. The anti-protons of FAIR will be injected into HESR, a slow ramping synchrotron and storage ring with excellent beam energy definition by means of stochastic and electron cooling. This allows to measure masses and widths of hadronic resonances with an accuracy of 50–100 keV. This is 10 to 100 times better than any e^+e^--collider experiment can be. In addition all quantum numbers can be directly produced and not only states with $J^{PC} = 1^{--}$ of a virtual photon. In the PANDA experiment, the anti-protons will interact with an internal target, either a hydrogen cluster jet or a high frequency frozen hydrogen pellet target to reach a luminosity of up to $2 \times 10^{32}\mathrm{cm}^{-2}\mathrm{s}^{-1}$.

Main goals of PANDA[3] are the precision spectroscopy of charmonium states, charmonium hybrids (states with gluonic degrees of freedom) and excited D mesons. Using nuclear wire or foil targets charm mesons in the nuclear medium are produced to search for in-medium mass modifications. Hypernuclei are produced to study interactions of hyperons in the nuclear potential.

PANDA will operate at an interaction rate of up to 10 MHz. Its spectrometer is based on two magnets, a solenoid with barrel-like detectors for large angle tracks at lower energies and a forward dipole for the high momentum part. In the solenoid a vertex detector of Silicon pixels and strips surrounds the interaction region. The momentum reconstruction is performed by the central tracker, either a straw tube tracker or a time projection chamber. Charged particle identification is done by time-of-flight measurements and a DIRC detector detecting internally reflected Cherenkov light in a quartz radiator. An electromagnetic crystal calorimeter will measure photons with high accuracy. In the forward directions tracking is performed by drift chambers. A RICH, an electromagnetic Shashlyk calorimeter and a hadron calorimeter complement the forward detection system. In addition a muon system outside the magnet yokes and at the very end of the spectrometer allows identification of muons in a large momentum range. An overview of the spectrometer is given in Fig. 2.

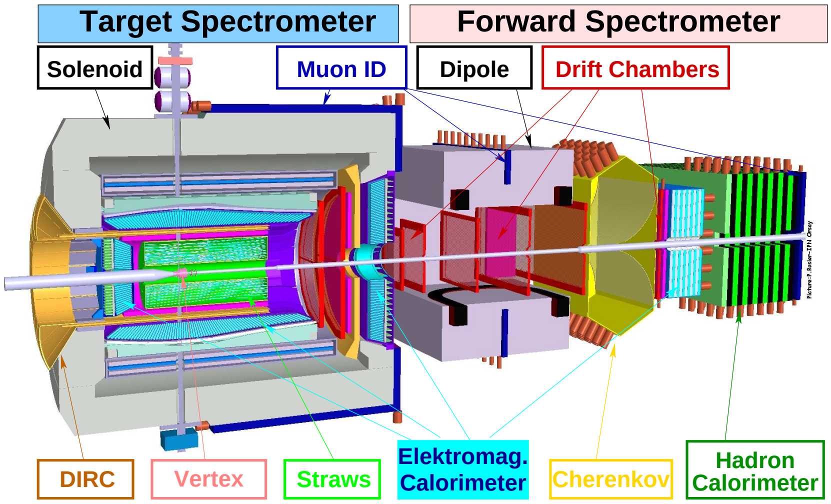

FIGURE 2. The PANDA Spectrometer

Nucleon Structure

Up to now the spin structure of nucleons is mostly investigated by deep inelastic lepton scattering experiments (DIS). An important but little known component of the nucleon spin is the transverse spin structure function, transversity. Due to its chiral odd nature it is accessible in DIS only through the deconvolution of fragmentation functions to be simulated or measured elsewhere thus introducing large systematic uncertainties and model dependence. An alternative process is the Drell-Yan lepton pair production in which a quark and an anti-quark from two colliding nucleons annihilate into a virtual photon and then into a lepton pair. Here, transversity can be accessed directly. At the BNL RHIC this process is used in collisions of polarized protons making use of the anti-quarks present in the nucleon sea. At FAIR's HESR this could be done by colliding polarized protons with polarized anti-protons giving much higher yield and asymmetries than with sea-quarks.

The anti-protons could be polarized at low energies using a dedicated polarizer ring by using the spin filter method based on a polarized atomic beam source. The polarized anti-protons would then be accelerated in HESR maintaining their polarisation by means of Siberian snakes.

The PAX detector[4] will perform the measurement of transversity and other polarisation related observables. Presently it is foreseen as asymmetric collider experiment optimized to detect electromagnetic final states with two charged tracks of high invariant mass. A clear identification of electrons is required to separate scattered electrons of the Drell-Yan mechanism from the large pion background using a Cherenkov detector. The detector is designed to also detect two-body hadron reactions using kinematical constraints, i.e. coplanarity and total momentum conservation. The momentum is determined by tracking inside and outside a toroidal magnet. Radiative processes can be detected by an electromagnetic calorimeter.

PAX is presently pursued as an additional option for FAIR depending on the feasibility of a reasonably high anti-proton polarisation.

OUTLOOK

The FAIR project organisation is accompanied by a an international steering committee dealing both with the scientific and technical aspects on one side and the financial and administrative matters on the other. Already now a community of more than 2000 physicists is attached to the various program advisory committees.

For the construction of FAIR 12 states from Europe and Asia have agreed to sign as members of an international consortium. The construction will proceed in three phases. Civil construction should take place from 2008. Until 2011 the new rare isotope beam facility is to be completed, until 2013 SIS 100 and the equipment for anti-protons will become operational. In 2015 the full facility should be completed.

ACKNOWLEDGMENTS

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